Fellenius, B.H., 2002. Side resistance in piles and drilled shafts. Discussion. ASCE Journal of Geotechnical and Geoenvironmental Engineering, Vol. 128, No. 5, pp. 446 - 448.

Discussion of "Side Resistance in Piles and Drilled Shafts" by Michael W. O'Neill

January 2001, Vol. 127, No. 1, 3–16.

Bengt H. Fellenius, M.ASCE[1]

[1]Principal, Urkkada Technology Ltd., 1010 Polytek St., Unit 6, Ottawa ON, Canada K1J 9H8. E-mail: bengt@urkkada.com

The author presents data from results of tests of 102-mm-diameter pipe pile in a 765 mm i.d. calibration chamber that show measured uplift resistance (pull) that is smaller than the compression (push) resistance and also mentions that measurements showed decrease of effective vertical stress near the model pile during pull and of increase during push. As shaft resistance is a function of effective overburden stress, the latter observation serves to explain the former.

The author also makes reference to work by De Nicola (1996), which purportedly shows that resistance in pull is smaller than in push. De Nicola based a theoretical model on the qualitative fact that in push the pile width increases, while in pull, it decreases—quantitatively determined as a function of the Poisson ratio of the pile material. Contraction of the pile width would reduce the effective horizontal stress against the pile surface (governed by an earth pressure coefficient, as it were), because the earth pressure moves toward the active phase. Similarly, expansion of the pile width would increase the effective horizontal stress because the earth pressure moves toward the active phase. However, for an ordinary pile size of about 300 mm diameter, the contraction/expansion movements of a pile due to the axial loads are in the range of about 0.02–0.10 mm. That such small values would have any effect on the unit shaft resistance are highly doubtful. Consider also that the shaft resistance, especially in the upper portion of a pile, is mobilized very early in a test and remains essentially constant thereafter (large strain degradation aside) during a continued increase of axial stress and associated continued contraction/expansion.

One must not mistake a lateral expansion movement to mean that the grains nearest the pile shaft would be pushed in between the grains one layer of grains at one grain diameter further away from the pile, nor, in the contraction mode, that the one-grain-diameter-further-away grains would move in to occupy the position of the initially nearest grains. Instead, the situation is akin to the behavior of sand in a simple-shear, constant-volume test in a large shear box, with the height of the soil about 0.2–0.5 m (equal to the zone of influence around a pulled or pushed pile). A change of this height of less than 0.1 mm, i.e., 0.05–0.02% of the height (thickness of the influenced zone), will have an insignificant effect on the volume of sand, on the normal stress, and on the ultimate shear force.

Moreover, the 0.1-mm movement is also insignificant in relation to the 5–10 mm movement necessary to fully mobilize the shaft resistance along the pile.

That shaft resistance in pull would be smaller than that in push has been suggested also by others. For example, Tschebotarioff and Palmer (1948) and Broms and Silberman (1964) reported results from laboratory tests indicating that shaft resistance in pull would be smaller than that in push. However, the tests involved small-scale model piles, where boundary conditions probably played a role. It is interesting to note that in addition to testing the units in push and pull, Broms and Silberman also tested the units in torsion (and found this shaft resistance to be somewhere between those in push and pull).

The discusser does not want to appear overly critical about laboratory and small-scale testing. However, full control of boundary effects is difficult to achieve without exchanging too much soil for instrumentation. Moreover, for many of the tests reported in the literature, the analyses of the test data have not properly considered the modeling rules, e.g., Altaee and Fellenius (1996). Full-scale tests performed in the field often do not confirm the observations in the laboratory. Tschebotarioff (1951), for example, indicated that when tests were performed in natural soil at depths of 6 and 15 m below the ground surface, no difference was obtained between the two directions of loading.

The discusser does not have access to De Nicola's thesis (DeNicola 1996), referenced by the author. However, details of the thesis results and the push–pull material and contention are also presented by De Nicola and Randolph (1993) and by Randolph et al. (1994). Both papers corroborate De Nicola's theoretical calculation by making reference to the results of three full-scale tests published by Beringen et al. (1979), Brucy et al. (1991), and Mansur and Kaufmann (1956). The mentioned three case-history papers are frequently referenced also by others as showing shaft resistance in pull to be smaller than that in push, for example, Jardine et al., (1998) and Chow et al. (1996). However, the discusser has looked up all three original case-history papers and find them not to be supportive of the push–pull contention.

The first of the three papers (Beringen et al. 1979) presents results from static push and pull (pull after push) loading tests in

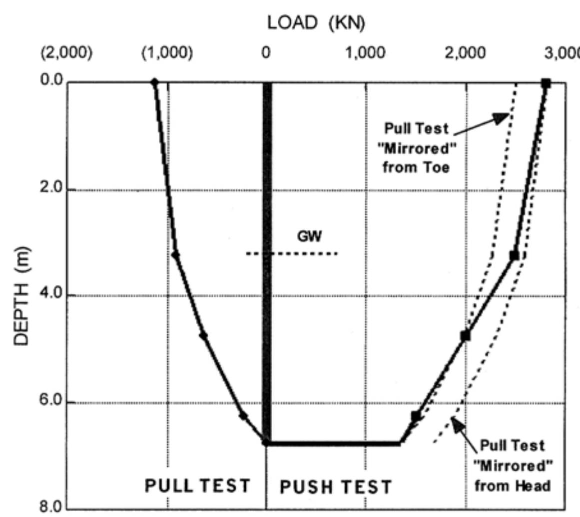

Fig. 1. Comparison of load distribution in push and in pull (data from Beringen et al., 1979).

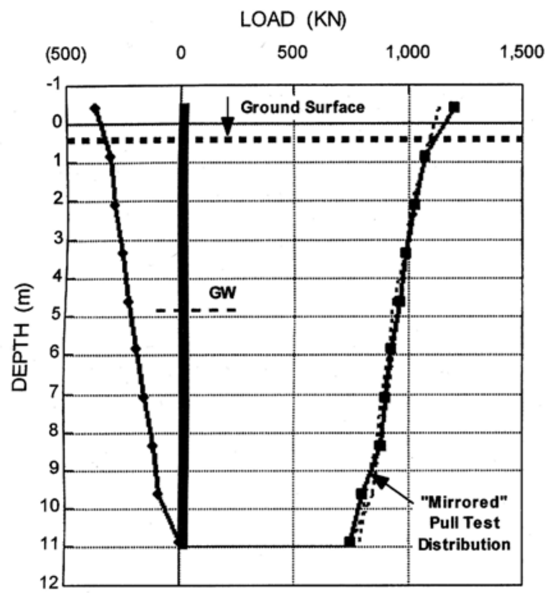

Fig. 2. Comparison of load distribution in push and in pull (data from Brucy et al., 1991).

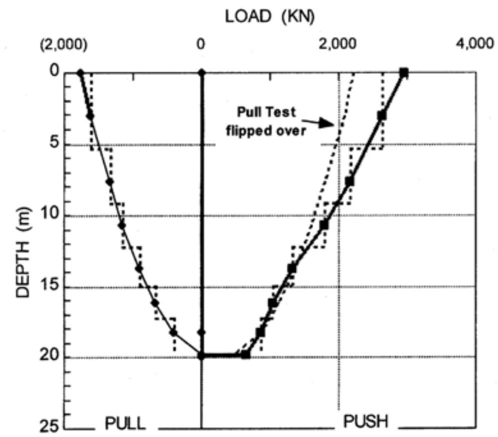

Fig. 3. Comparison of the slopes of load distribution in push and in pull (data from Mansur and Kaufmann, 1956).

Friesland, The Netherlands, on 356-mm diameter, about 7-m-long instrumented piles driven in very dense overconsolidated sand. The test results from the two piles are very similar. Fig. 1 presents the load distribution results from one pile. To facilitate the comparison between the pull and push results, the distribution of the pull test has been "mirrored" (flipped over) to the push test distribution. Taken at face value, the data indicate that, but for a small zone between the depths of about 3.5 and 4.5 m, the shaft resistances in push and pull are equal (as evidenced by that the curves are parallel). Because Beringen et al. (1979) made only approximate compensation for residual load and zero drift of gauges occurred requiring uncertain adjustment of readings, no definite conclusion can be stated about whether one or the other test direction produced a smaller or larger shaft resistance, that is, the data cannot be used in support of the contention.

The second paper (Brucy et al., 1991) presents results from static pull and push (push after pull) loading tests in Dunkerque, France, on 324-mm diameter, about 11-m-long instrumented piles driven in a compact sandy deposit. The test results from the two piles are very similar. Fig. 2 presents the load distribution results from one pile. Again, the distribution of the pull test has been mirrored (flipped over) to the push test distribution. Obviously, as for the Beringen (1979) results, the results do not support the pull/push contention. Brucy et al. (1991) state that no correction was made for residual load of the piles. However, Chow et al. (1996), in referencing the same tests, mention that Brucy et al. (1991) did make a correction by subtracting the toe resistance that was measured in the pull test and distributing it proportionally along the shaft.

The third paper (Mansur and Kaufmann 1956) presents results from static push and pull (pull after push) loading tests in Louisiana, on telltale instrumented, closed-toe 533-mm pipe piles. The piles were driven in a 15-m-deep excavation to embedments of 20 m through an upper layer of 14.6 m of silt and clay deposited on silty sand. The test piles were instrumented with six levels of telltales spaced evenly in the pile. Two 20-m-long piles, piles 2 and 6, were tested in push and pull. The telltale measurements were converted to load and used to present the load distribution during the static loading tests—a push test using a single cycle of loading and unloading followed by a pull test, also a single loading and unloading cycle. The Pile 2 data are consistent, while Pile 6 data are quite scattered. The authors state that residual load (locked-in load) was *assumed* not to be present in the pile *before* the push test. They do mention, however, that compression remained in the pile *after* the push test. Moreover, they write that the data from the pull test show that residual load has affected the calculated values of load in the pile (data evaluation indicated an apparent tension toe load). They adjusted the measurements to show zero toe load in the pull test, but they appear to have done little other adjustment to correct the load distribution for residual load, stating the distribution plots to be "*reasonably accurate*." The authors also state that "*the difference between the two curves* (push distribution and pull distribution) *at a given load is attributed to the elastic strain in the pile that results from locked-in stresses*."

The load distribution data for Pile 2 are presented in Fig. 3 with the distribution of the pull test mirrored. The comparison shows an agreement between the shaft resistances for the lower about 8 m length of the pile. Above this depth, the shaft resistance appears to be smaller, as it should, due to that the residual load gives an apparent increase of shaft resistance in push and decrease of shaft resistance in pull. The true shaft resistance lies somewhere in between the shown distributions and the test data do not support any conclusion that the shaft resistance would be a function of direction of movement.

For reasons that are obvious from the quoted field test data, the discusser does not find that the current state of the art demonstrates that a difference would exist in shaft resistance depending on the upward/downward direction of movement of the pile. However, the discusser yet very much agrees with the author's recommendations for caution when designing for uplift. If the capacity of a pile would be exceeded in compression loading, the result would normally show up as excessive differential settlement, crack development, and other undesirables affecting the serviceability of the structure. In contrast, exceeding the capacity of a pile in uplift could result in large continuing movements and, ultimately, collapse of a foundation, a profoundly less desirable consequence and, therefore, a condition warranting a larger factor of safety.

References

Altaee, A., and Fellenius, B. H. (1994). "Physical modeling in sand." *Can. Geotech. J.,* 31(3), 420–431.

Beringen, F. L., Windle, D., and VanHooydonk, W. R. (1979). "Results of loading tests on driven piles in sand." *Proc., Conf. on Recent Developments in the Design and Construction of Piles,* The Institution of Civil Engineers, ICE, London, March 21–22, 213–225.

Broms, B. B., and Silberman, J. O. (1964). "Skin friction resistance for piles in cohesionless soils." *Sols-Soils,* 10, 33–41.

Brucy, F., Meunier, J., and Nauroy, J. F. (1991). "Behavior of a pile plug in sandy soils during and after driving." *Proc., 23rd Annual Offshore Technology Conference,* Houston, OTC 6514, 145–154.

Chow, F. C., Jardine, R. J., Nauroy, J. F., and Brucy, F. (1996). "Time-related increases in the shaft capacities of driven piles in sand." *Geotechnique,* 47(2), 353–361.

De Nicola, A., and Randolph, M. F. (1993). "Tensile and compressive shaft capacity of piles in sand." *J. Geotech. Eng.,* 119(12), 1952–1973.

Jardine, R. J., Overy, R. E., and Chow, F. C. (1998). "Axial capacity of offshore piles in dense North Sea sand." *J. Geotech. Geoenviron. Eng.,* 124(2), 171–178.

Mansur, C. I., and Kaufman, R. I. (1956). "Pile tests, low sill structure, Old River, Louisiana." *J. Soil Mech. Found. Div., Am. Soc. Civ. Eng.,* 82, 715–743.

Randolph, M. F., Dolwin, J., and Beck, R. (1994). "Design of piles in sand." *Geotechnique,* 44(3), 427–448.

Tschebotarioff, G. D., and Palmer, L. A. (1948). "Some experiences with tests on model piles." *Proc., 2nd Int. Conf. on Soil Mechanics and Foundation Engineering,* ICSMFE, Rotterdam, September, 2, 195–199.

Tschebotarioff, G. D. (1951). *Soil mechanics, foundations, and earth structures,* McGraw-Hill, New York, 440; 2nd Ed., 1979, 230.